

ASL-CR-78-0103-1



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# ROCKETBORNE OZONESONDE UTILIZING CHEMILUMINESCENCE TO MEASURE ATMOSPHERIC OZONE

**MAY 1978** 

AU NO.

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UNDER CONTRACT DAAD07-75-C-0103

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US Army Electronics Research and Development Command

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#### 20. ABSTRACT (cont)

as its dependence upon the flow rate are described. Test results obtained at White Sands Missile Range (32 N) are compared to those of other experimenters.





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#### 1.0 INTRODUCTION

Scientists are aware and the general public is becoming more and more aware that life on earth is possible only because the atmospheric ozone layer exists. Ultraviolet light from the sun is absorbed by the ozone layer, preventing ultraviolet rays in quantities dangerous to human existence from reaching the earth. Were the ozone layer to be destroyed, there would be no such safety shield protecting life on earth.

Medical experts may have linked excessive ultraviolet light exposure to cancer and are justifiably concerned that even partial deterioration of the ozone layer would allow more ultraviolet light to penetrate to the earth's surface, increasing in number the victims of cancer.

We know that ozone is very unstable and that it disassociates readily.

The ozone "layer" is really an ozone equilibrium, a balance between ozone being created and destroyed. Atmospheric contaminants such as may be released from aerosol cans or jet engine exhaust may rise high enough to reach the ozone layer. 

If they do, the ozone equilibrium could be upset, with only negative consequences.

The only way to "keep an eye" on the ozone layer is to measure it, and the best way to measure it at altitudes higher than 30 km is via sounding rockets.

An ideal way to measure the ozone layer is to incorporate an ozonesonde that is compatible with meteorological rockets that are currently being launched

daily from facilities around the world. Such a system, if feasible, would provide a necessary safety measure at minimal added costs.

The detection method is to use a sensor disk coated with a Rhodamine B solution, which, when contacted by ozone, results in a light-emitting chemical reaction (a chemiluminescent reaction). The measurement technique is to measure the intensity of the light emitted due to the ozone-Rhodamine B reaction. Theoretically, the greater the intensity, the more ozone there is.

The detection system must be designed so that the light meter measures only light emitted due to the chemiluminescence. Extraneous sunlight, if visible by the light meter, would give false ozone readings. Therefore, the ozonesonde design must allow flow of a representative air sample while simultaneously blocking out stray light. One proposed design is shown in Figures 1.1 and 1.2.

The purpose of the research effort described in this report was to define the quantitative relationship between the intensity of the emitted light and the ozone concentration and to reveal and (if possible) solve other problems introduced as a result of the research effort.

Consistency and repeatability of results were investigated during Sensitivity Tests. Several questions arose in this area, none of which precluded the chemiluminescent technique for measuring ozone.

Detector output versus ozone concentration as functions of flow rate and pressure were investigated, though on a limited basis due to economic constraints

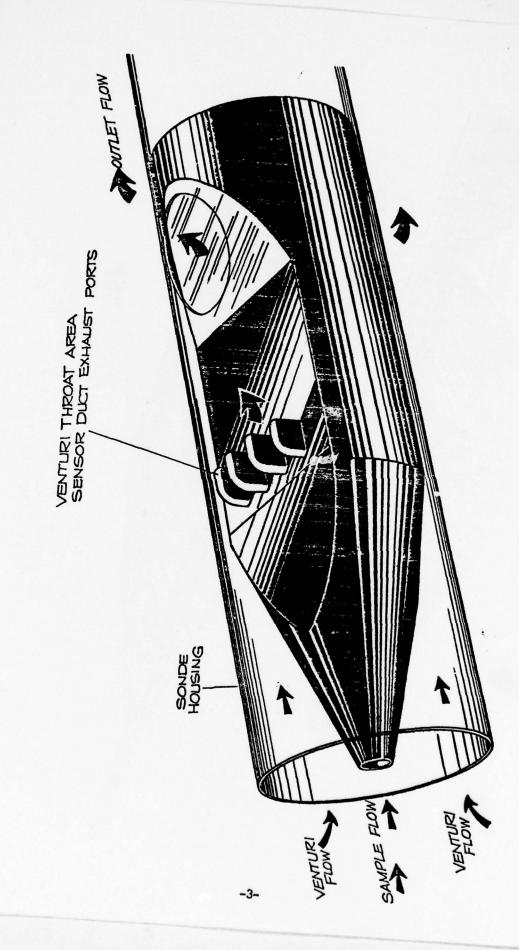


FIGURE 1.1 OZONESONDE AIR SAMPLING PROBE CONFIGURATION

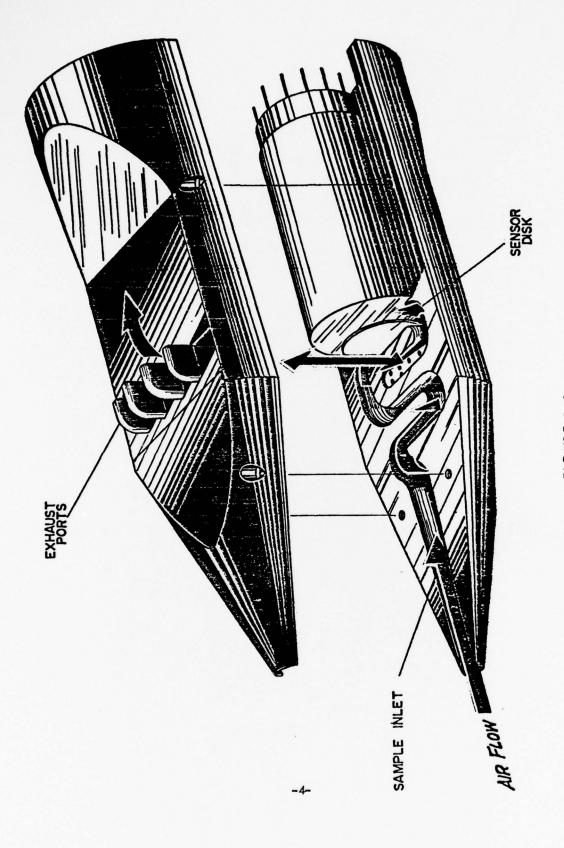


FIGURE 1.2 OZONESONDE AIR SAMPLING PROBE CONFIGURATION



of the contract. These tests revealed the importance of flow rate on the data reduction technique. Because in-flight flow metering is too expensive to be practical, flow rates through the ozonesonde ducts must be calculated. (See SDC TM-1414.) To verify flow rate calculations, blowdown tests were conducted.

Inlet losses were investigated, but they were found to be insignificant within the range of tests conducted.

Finally, vibration tests were conducted in order to determine whether vibrations experienced during flight would be sufficiently forceful to cause the sensor material to flake off, resulting in decreased sensitivity. They were not.

As a result of these tests, the conclusion drawn is that the rocketborne ozonesonde employing the chemiluminescent technique for measuring atmospheric ozone is feasible. The following sections describe test results and define the atmospheric ozone data reduction technique.

#### 2.0 SENSITIVITY TESTS

#### 2.1 Introduction

The proposed technique for measuring atmospheric ozone incorporates a photomultiplier to measure the light emitted as a result of a chemiluminescent reaction between ozone and Rhodamine B, a solution of which is
coated on the ozonesonde sensor disk surface. Theoretically, there is a measurable relationship between the amount of ozone reacting with Rhodamine B
and the intensity of the resulting emitted light.

The purpose of the Sensitivity Tests was to study the relationships between ozone concentration and detector (photomultiplier) output. Clearly, consistent and repeatable results (per individual disks) are mandatory if ozone measurements are to be accurate and valid. To facilitate repeatability, an ozone generator that would enable known amounts of ozone to be created at repeatable rates was constructed. Ozone is created by bombarding a mixture of oxygen and nitrogen gases with ultraviolet light – as is done in the atmosphere, where the sun provides the ultraviolet light (UV) source. The more UV there is, the more ozone is generated, and the relationship is a direct proportion. What the ozone generator does is uncover/cover a UV lamp at a constant rate, such that more/less ozone is created. A Dasibi ozone monitor measures the amount of ozone created, and a strip chart recorder can be (and was) used to record the Dasibi ozone concentration measurements and the photomultiplier output. Figure 2.1 is a schematic of the test setup.

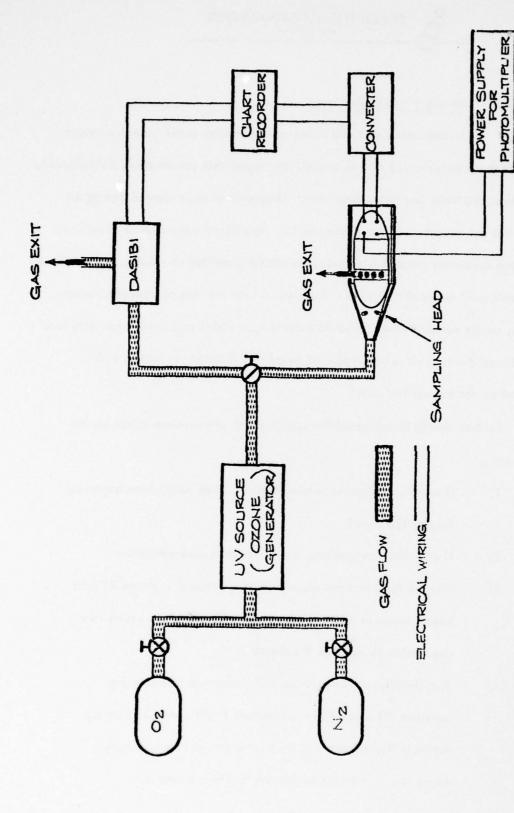


FIGURE 2.1, TEST SETUP

#### 2.2 Results and Observations

Initial tests monitored ozone concentration versus detector output.

Results of these tests showed that consistent and repeatable results could be achieved, but to do so the disks had to be sensitized. Unsensitized disks showed consistent trends, but not consistent quantitative results. Sensitized disks showed consistent trends and consistent, repeatable, and predictable quantitative results. To say disks are "sensitized" means that they are "warmed up" for the task of measuring ozone.

That is, ozone concentration versus detector output stabilization has been achieved in sensitized disks. This is accomplished merely by flushing the system with ozonized air for a specified time.

Further testing investigated the sensitization phenomenon to answer the questions:

- 1) If exposure to ozone sensitizes disks, does zero ozone exposure desensitize them?
- 2) If so, what time periods are involved in desensitization?
- 3) What is the quantitative relationship between a period of zero ozone exposure and the subsequent and immediate ozone flux required to resensitize the disks?
- 4) Specifically, is the relationship discovered in answering question #3 compatible with actual flight events? That is, during a flight there will be a brief period of zero ozone exposure. If that period is such that significant disk

desensitization occurs, how much subsequent ozone exposure is required to resensitize the disk? Is the amount of ozone present at high altitudes sufficient in quantity to accommodate disk resensitization at flow rates expected during flight?

To answer these questions, the same test setup as shown in Figure 2.1 was used. The test procedure was to sensitize the disks by flushing with ozone of 1 part per million by volume (ppmV) concentration for ten minutes at 1 liter/minute flow rate. A cycle run was made to measure ozone concentration versus photomultiplier output for a sensitized disk. (During initial tests of this kind two more cycles were conducted and the subsequent, repeatable results proved the disks to be sensitized.)

The disk then sat idle for a specified time, after which cycle runs were made. Data taken after an idle period were compared with pre-idle data, and the difference showed the effect of zero ozone exposure for that idle period.

Results were that periods of zero ozone exposure did cause disk desensitization, resulting in an inconsistent overshoot phenomenon. That is, desensitized disks exhibited a greater photomultiplier response than sensitized disks.

When the ozone concentration was held constant, the desensitized disk's photomultiplier response decreased until stabilization (resensitization) occurred. The time required for stabilization varied, depending upon the degree of desensitization and the ozone flux through the sensor duct during resensitization.

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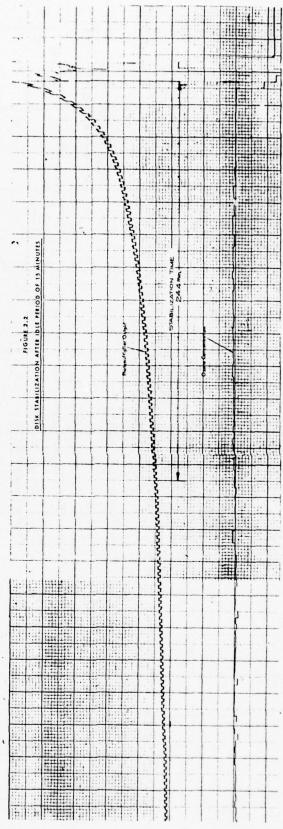
Figure 2.2 exhibits the overshoot phenomenon observed in desensitized disks. The particular disk shown in Figure 2.2 was left idle for fifteen minutes. Figure 2.3 shows the same disk's photomultiplier response after an idle period of two minutes.

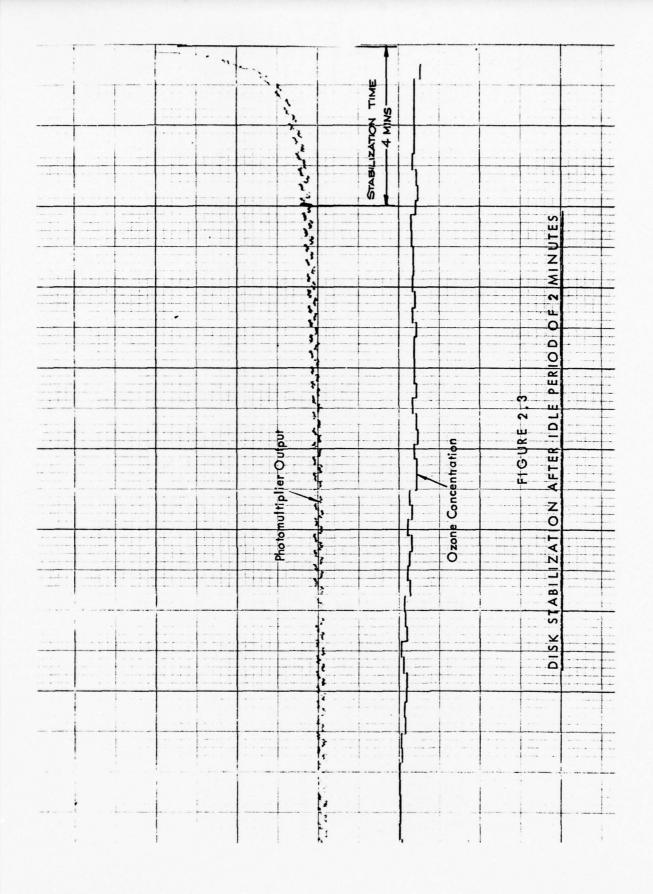
Comparison of Figures 2.2 and 2.3 shows that the longer the idle period of zero ozone exposure, the stronger the disk desensitization, the greater the overshoot and the longer the period required to resensitize the disk.

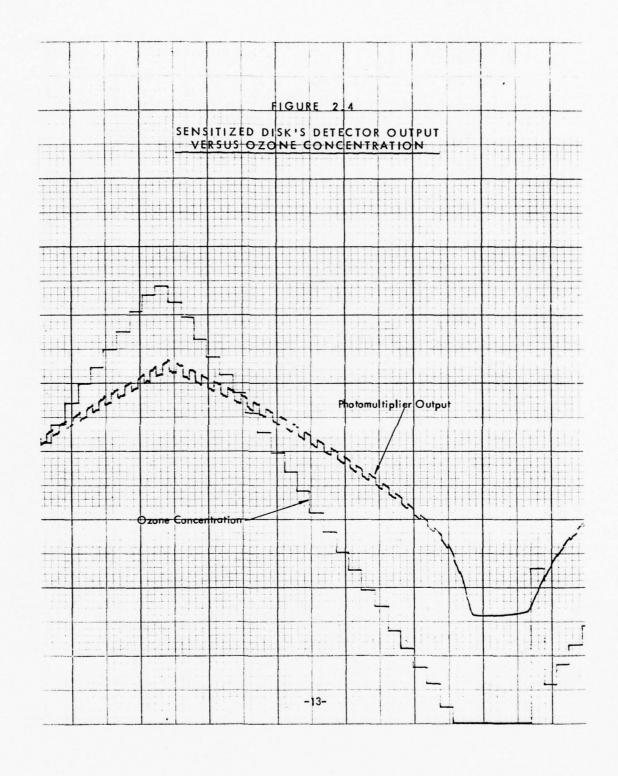
The effect of overshoot is to flatten out the photomultiplier response curve. In isolated cases, the overshoot effect even reversed the slope of the photomultiplier response curve! Clearly, if photomultiplier response is to be used to show the amount of ozone present, the overshoot phenomenon cannot be present. That is, disks must be sensitized.

Figure 2.4 shows the ozone concentration versus photomultiplier output for a sensitized disk. Note how, after an initial bend, the response is relatively linear and is therefore very useful for measuring ozone.

Figure 2.5 shows the same disk after an idle period of 15 minutes. Note how the photomultiplier response overshoots the reading of the same disk when sensitized for the same early ozone concentrations. As the disk becomes more exposed to ozone, it becomes resensitized, and if the ozone concentration were held constant, the photomultiplier response would decrease until stable. But the ozone concentration is increasing, so the photomultiplier response is also increasing, although its rate of increase is decreasing and will continue to decrease until the disk is resensitized.







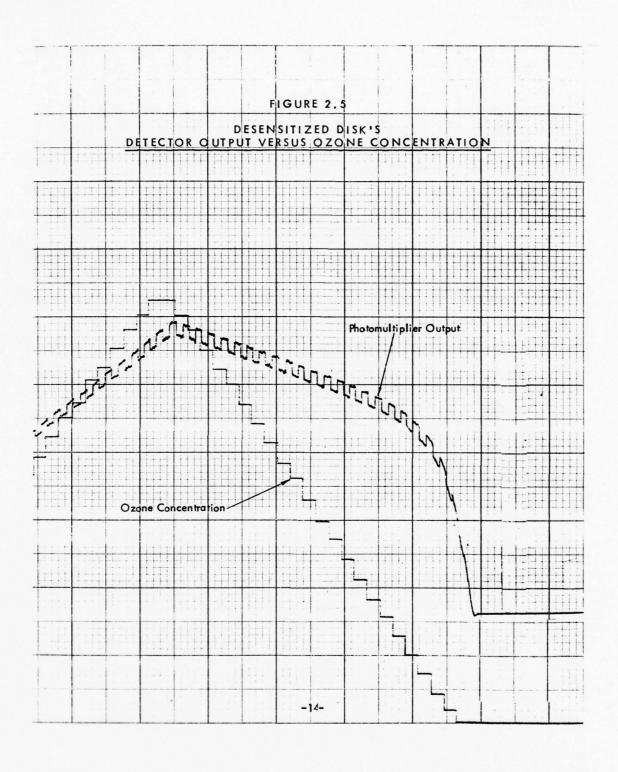


Figure 2.6 shows an example of a drastic overshoot in photomultiplier response. Clearly, this response is unacceptable for ozone measurements. For this case, there is no way to relate photomultiplier response to a specific ozone concentration.

When the disk of Figure 2.6 is sensitized, its response curve is stable, as shown in Figure 2.7. Clearly, the disk – when sensitized – is useful for measuring ozone.

Thus, the answers to the first two questions are:

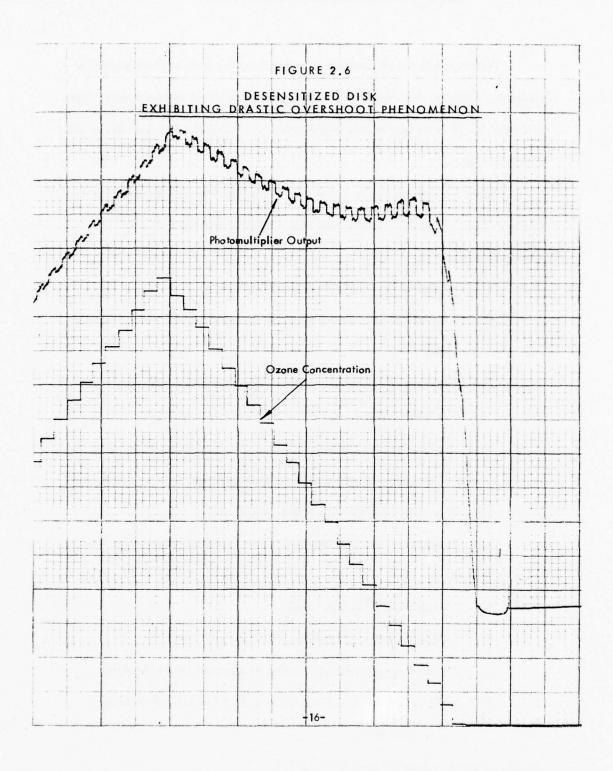
- Periods of zero ozone exposure do result in disk desensitization,
   and
- Idle periods as brief as two minutes can cause measurable disk desensitization.

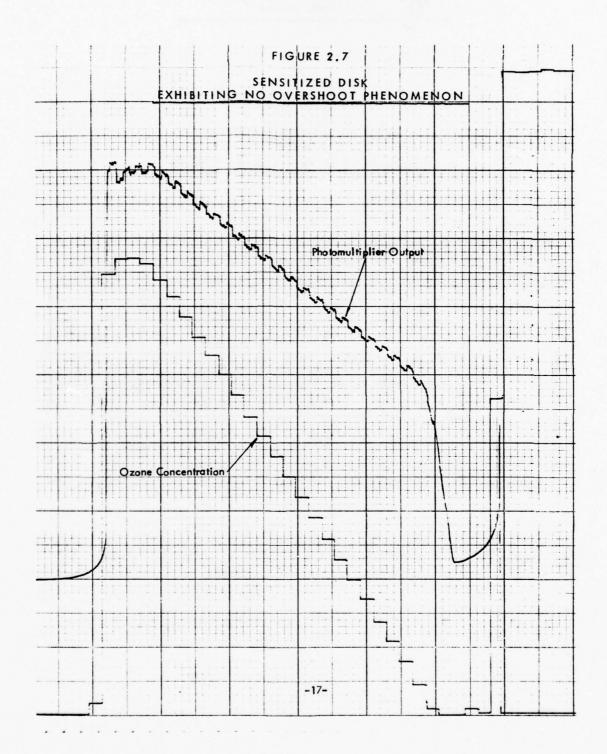
Since the time between liftoff and the start of ozone measurements is on the order of two minutes, measurable disk desensitization can occur, even if disks are continuously flushed with ozone until liftoff.

Test procedures to measure resensitization versus desensitization times were as follows:

- 1) Disks were fully sensitized.
- 2) Disks underwent a specified idle period.
- Disks were flushed with ozone at constant concentrations,
   the stabilization was recorded and the stabilization time
   was measured.

Results of these tests are shown in Table 2.1.





#### TABLE 2.1

# DISK RESENSITIZATION VERSUS DESENSITIZATION (IDLE) TIMES

Disk #	ldle Period	Resensitization Time	Concentration (ppmV)	Flow Rate (I/min)
1104-01Y	21	11.	0.28	1
	4	2,	0,39	1
	2	1.6	0.10	1
	2	1.2	0,20	1
	2	1,6	0.265	1
	2	1.2	0.385	1

More meaningful data will be achieved if we relate resensitization by ozone flux through the sensor duct.

From Table 2.2, a zero ozone exposure period of two minutes requires an ozone flux on the order of  $10^{14}$  molecules/second for two minutes in order to resensitize the disk.

The questions are: what is the ozone flux at high altitudes, and how long will it take to resensitize the disk with such an ozone flux?

The calculated ozone flux expected at altitude is on the order of 10<sup>12</sup> molecules/second. Such a small ozone flux would require approximately two hours to fully resensitize the disk. Such a long resensitization time seemingly should preclude testing but it does not for the following reasons:

As ozone flux decreases, the magnitude of the overshoot decreases.

At the low limit, despite the overshoot, the photomultiplier output is very nearly equal to the output of a stabilized disk for the same concentration, i.e., the overshoot is negligible, and it will remain negligible until greater ozone number density measurements need to be made; however, when the ozone concentration is high enough to cause the overshoot to be non-negligible, the resensitization times for those higher concentrations are shorter, on the order of two minutes. Since the descent phase of the flight is on the order of 30 – 40 minutes, a two minute resensitization time is acceptable.

Also, the ozone flux does not remain at the low level for very long. It continually increases with the increasing ozone levels present at lower altitudes.



TABLE 2.2

#### RESENSITIZATION TIME VERSUS OZONE FLUX

Disk #	Idle Period (min)	Ozone Flux (molecules/sec)	Resensitization Time (min)
1104-01Y	21	1.25 × 10 <sup>14</sup>	11
	4	1.72 × 10 <sup>14</sup>	2
	2	0.447 × 10 <sup>14</sup>	1.6
	2	0.895 × 10 <sup>14</sup>	1.2
	2	1.19 × 10 <sup>14</sup>	1.6
	2	1.72 × 10 <sup>14</sup>	1.2

#### Observations

The sensitivity tests led to the following observations:

- 1) Exposure to ozone sensitizes disks.
- 2) Zero ozone exposure desensitizes disks.
- Even zero ozone exposure periods as brief as two minutes result in measurable disk desensitization.
- The effect of disk desensitization is an overshoot in photomultiplier output, i.e., there is a greater photomultiplier response for a desensitized disk than for a sensitized one. The overshoot decreases with decreasing concentration.
- 5) Disks desensitized for two minutes require an ozone flux of  $10^{14}$  molecules/second for two minutes in order to resensitize the disks.
- of approximately two minutes (the time between liftoff and sonde exposure to atmosphere); therefore, to resensitize disks in flight, an ozone flux of 10<sup>14</sup> molecules/second for two minutes is required.
- 7) There is not enough ozone above 70 km altitude to accommodate the ozone flux required to resensitize flight disks; but, because the overshoot in photomultiplier output caused by desensitized disks decreases with decreasing ozone concentration,



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the overshoot is low for low ozone concentrations. Above 70 km, the ozone concentration is so low that the effect of overshoot is negligible.

#### Conclusions

- Disk sensitivity is compatible with rocketborne ozonesondes
   utilizing the chemiluminescent technique for measuring atmospheric ozone.
- 2) Disks must be sensitized prior to flight by flushing with 1.0 ppm ozonized air, preferably until liftoff.
- 3) Disks should be calibrated as close to liftoff as practical.

#### 3.0 DETECTOR OUTPUT VERSUS CONCENTRATION

#### 3.1 Flow Rate Dependency

Flow rates through the ozonesonde sampling duct during an actual flight are expected to vary between 6 and 300 liters per minute. Flow rates of 6 liters per minute can be readily achieved in the laboratory. Flow rates on the order of 300 liters per minute require expensive vacuum chamber/pump systems that were not available within the financial constraints of this contract; therefore, tests measuring detector output versus concentration as a function of the full range of flow rates expected during flight were not conducted. Flow rate dependency of limited scope is included in Section 3.2.

#### 3.2 Pressure Dependency

Low pressure tests were conducted using the test setup schematicized in Figure 3.1. Essentially what was done was to sensitize the disk by flushing with ozonized air for approximately twenty minutes, then calibrating at ambient pressure, evacuating the belliar to a low pressure, resensitizing the disk, and finally calibrating at the low pressure.

Figure 3.2 compares results at ambient pressure with those at low pressure.

While the system was set up at low pressure, tests were conducted to show the effect of small changes in flow rate on detector output at low pressure. Those results are also depicted in Figure 3.2.

As shown by Figure 3.2, small changes in flow rate result in measurable detector output differences. During flight, large flow rate differences (on the order of 200 liters per minute) are expected.

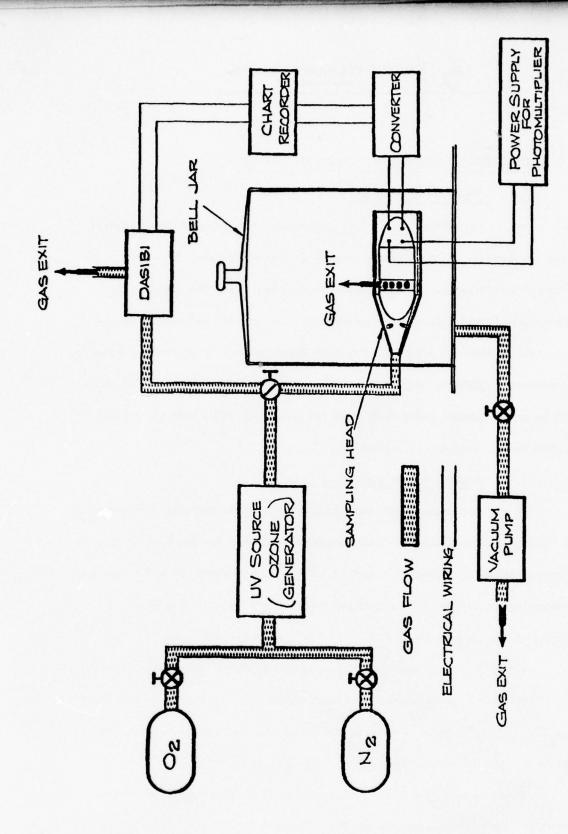
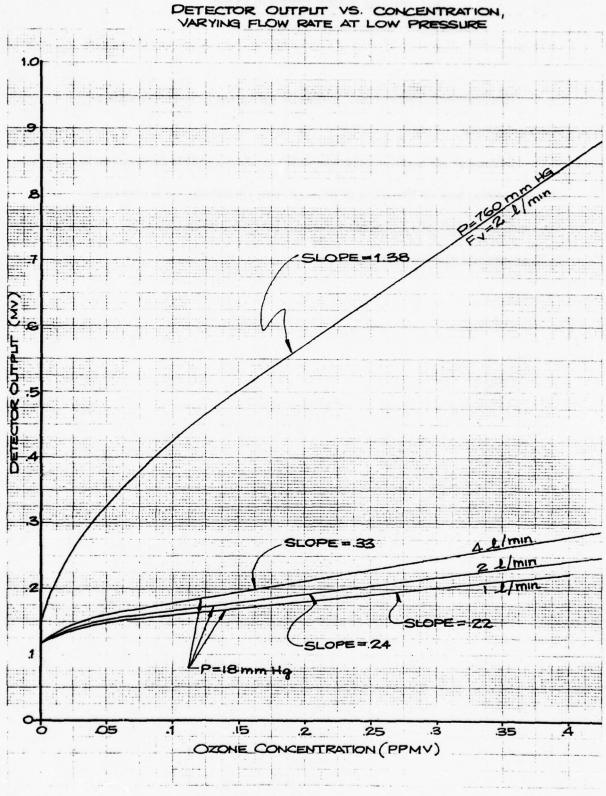


FIGURE 3.1, TEST SETUP

FIGURE 3.2



The question is, what effect will large variations in flow rate have on detector output?

To answer this question experimentally requires sophisticated vacuum chamber testing beyond the scope of this contract; therefore, we must answer the question analytically. Appendix A shows how the detector output is affected by flow rate and altitude effects.

#### 4.0 BLOWDOWN TESTS

Previous sections have shown that atmospheric ozone data reduction depends on flow rate through the ozonesonde duct. Because in-flight flow-metering is too expensive, flow rate versus altitude is determined by calculation. The difference between the theoretical, calculated flow rate and that observed experimentally is due to friction, assuming the calculation to be otherwise correct. As a result of the blowdown test, the calculated friction factor can be adjusted to make the calculated flow rate agree with that measured in the lab. Friction factors are independent of altitude; therefore, if the flow rate calculation technique is correct, then if the calculated flow rate agrees with the observed flow rate at any one altitude (the test altitude, for example), then the calculated flow rate will agree with the observed flow rate at any and all other altitudes.

Flow rates through two ozonesonde sampling heads of different designs were measured by doing blowdown tests. Each head was mounted (in turn) into a vacuum chamber such that the ozonesonde duct entrance was at ambient pressure, and the exit was at vacuum chamber pressure. After plugging the ozonesonde duct entrance and sealing all sources of possible leaks, the vacuum chamber was evacuated to a pressure of about 60 mm of mercury. At time zero the duct entrance plug was removed; therefore, air flowed through the sampling duct into the vacuum chamber. By timing the measured pressure increase within the chamber, the flow rate through the duct was calculated, as follows:

$$F_V = \frac{V}{P} \frac{dP}{dt}$$

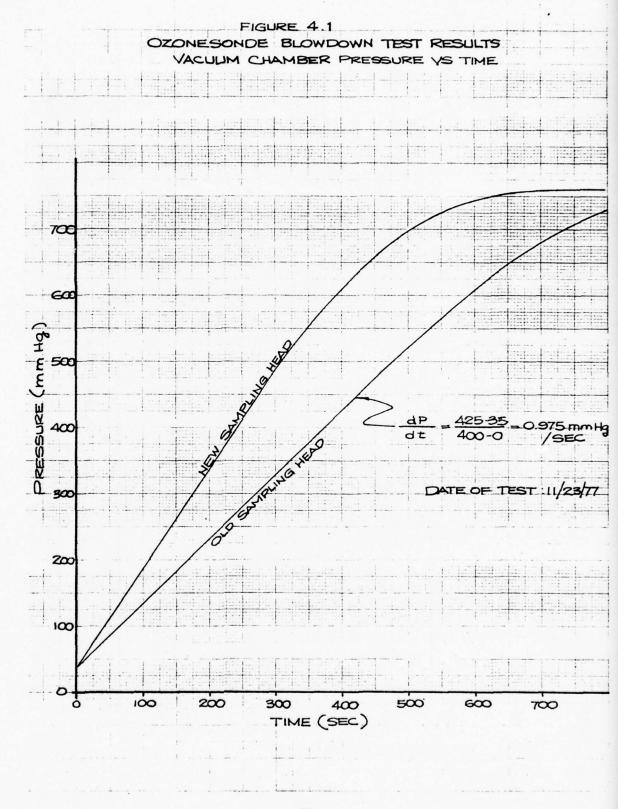
where  $F_V = \text{volume tric flow rate}$ 
 $V = \text{vacuum chamber volume}$ 
 $P = \text{vacuum chamber pressure}$ 
 $\frac{dP}{dt} = \text{slope of chamber pressure versus time curve}$ 

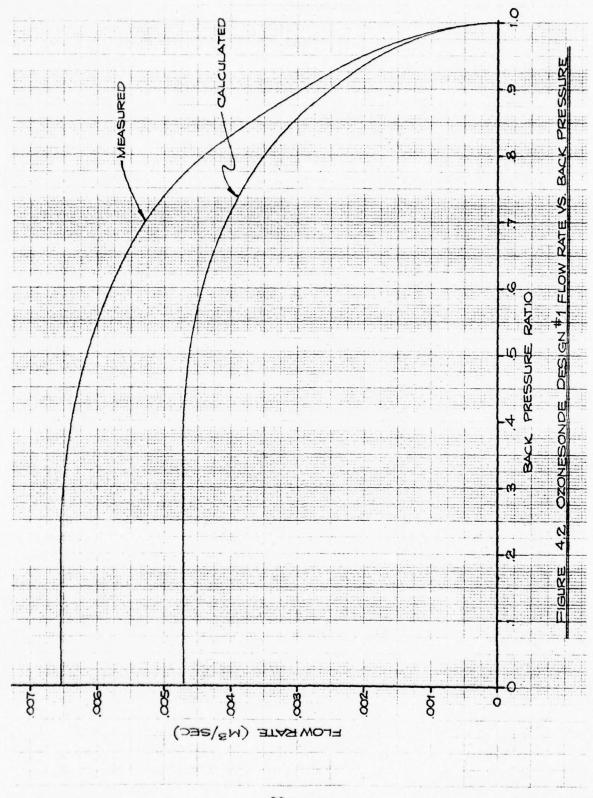
This expression is derived in Appendix B.

Ozonesonde blowdown test results are plotted in Figures 4.1 and 4.2. Vacuum chamber pressure versus time is shown in Figure 4.1, while Figure 4.2 shows ozonesonde sampling duct #1 flow rate versus back pressure ratio. Back pressure ratio is the ratio of duct back pressure to duct entrance pressure.

Using techniques defined in Appendix C, the flow rate was calculated.

Differences between the calculated and measured flow rates for ozonesonde design #1 are shown in Figure 4.2. To accurize flow rate calculations so that the flow rate agreed with the measured rate, loss factors were adjusted. For ozonesonde head design #1, the loss factor was changed from 6.15 to 3.90. For ozonesonde design #2, the loss factor was estimated to be 3.00.







### 5.0 INLET LOSSES DETERMINATION

Inlet losses were determined by first calibrating using the setup schematicized in Figure 5.1, then calibrating per the setup shown in Figure 5.2. Comparison of results yielded the inlet losses.

Within the range of tests conducted (flow rates varied from 1 to 12 liters per minute, pressures varied from 10 to 100 millibars) no significant losses were measured.

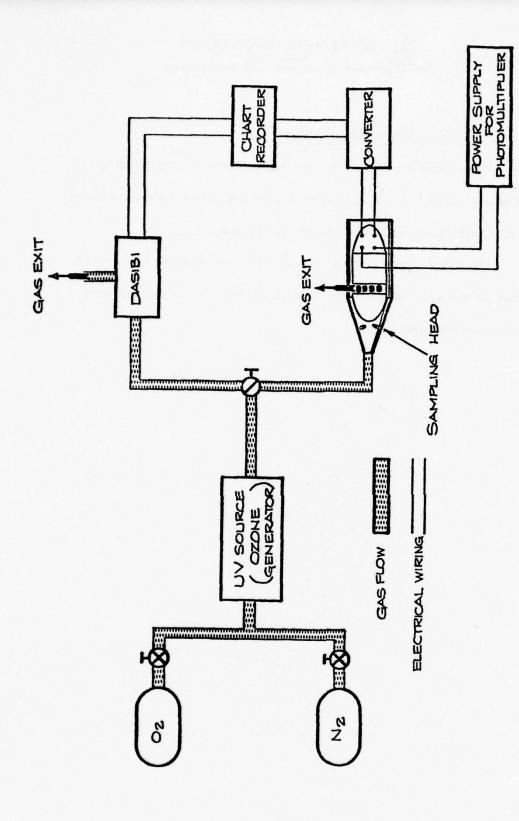


FIGURE 5.1, TEST SETUP

FIGURE 5.2, TEST SETUP

#### 6.0 VIBRATIONS TEST

A sensor disk was mounted on an ultrasonic vibrator and shaken for three minutes to simulate flight conditions. There was no physical evidence of flaking of sensor material and calibrations run prior to and after vibration testing showed no decrease in sensitivity.

Vibrations expected during flight will not cause flaking of sensor material; therefore, vibrations expected during flight will not alter disk sensitivity.

### 7.0 THE ATMOSPHERIC OZONE DATA REDUCTION TECHNIQUE

Calibration of the detection system will be in the form of ozone concentration (ppmV) versus detector output. The calibration curve will be converted via computer to ozone number density versus detector output, as follows:

$$(N_o)_{cal} = \frac{C A_o P_o}{m_w} \frac{P_{cal}}{P_o} S (10)^{-6},$$

where

 $(N_o)_{cal}$  = calibration ozone number density, molecules/cm<sup>3</sup>

C = ozone concentration, ppmV

A<sub>o</sub> = Avogadro's Number, molecules/mole

Po = ozone density at reference pressure, grams/liter

m<sub>w</sub> = ozone molecular weight, grams/mole

Po = ozone density reference pressure, inches Hg

P<sub>cal</sub> = calibration ambient pressure, inches Hg

S = conversion factor, liters/cm<sup>3</sup>

10<sup>-6</sup> = one part per million

Because

 $A_{0} = 6.02 \times 10^{23}$ 

 $\rho_{o} = 2.144,$ 

 $P_0 = 29.92,$ 

 $m_w = 48$ , and

 $S = 10^{-3},$ 

the above expression reduces to:

 $(N_0)_{cal} = 8.9871 (10^{11}) C P_{cal} molecules/cm<sup>3</sup>$ 

Thus, the calibration curve will have been converted to ozone number density versus detector output.

Flight data acquires detector output versus altitude, which derives from the calibration curve the uncorrected ozone number density versus altitude.

Appendix A shows how the number density is corrected for flow rate and altitude effects by the factor  $\frac{F_V}{\lambda}$ , where  $F_V$  = volumetric flow rate, and  $\lambda$  = mean free path. Thus, the final data reduction expression is

$$(N_o)_{alt} = (N_o)_{cal} \times \frac{\left(\frac{F_v}{\lambda}\right)_{alt}}{\left(\frac{F_v}{\lambda}\right)_{cal}}$$
, where

 $(N_0)_{alt}$  = ozone number density at altitude

(No)cal = calibration number density producing the same detector output observed at altitude

 $\left(\frac{F_{v}}{\lambda}\right)_{alt}$  = volumetric flow rate to mean free path ratio at altitude

 $\left(\frac{F_{v}}{d}\right)_{cal}$  = ratio during calibration

By reducing the data in this manner for a number of altitudes, an atmospheric ozone profile may be generated and plotted. The ozone profile shown in Figure 7.1 was generated using the data reduction technique defined in this section. The computer output for the data reduction is presented in Appendix D.

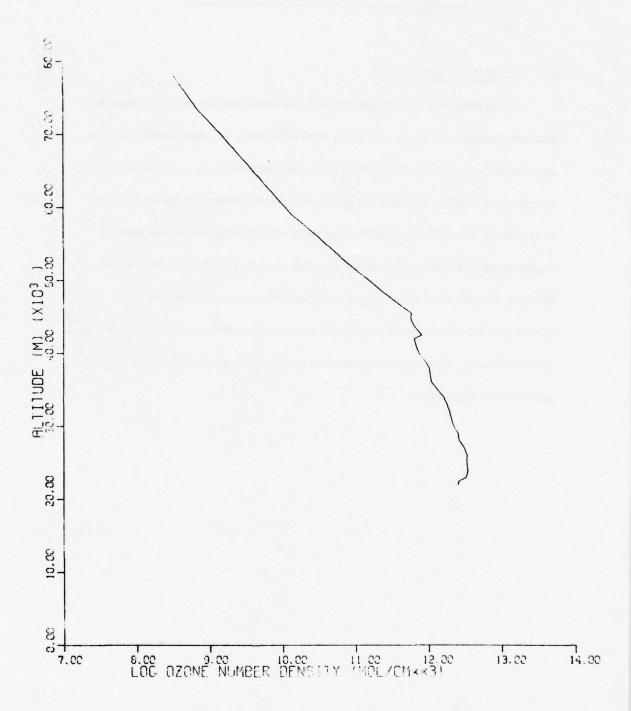


FIGURE 7.1, ATMOSPHERIC OZONE PROFILE

#### 8.0 CONCLUSIONS

Rocketborne ozonesondes can use the chemiluminescent technique to measure atmospheric ozone. To do so most efficiently requires sensitizing the sensor disk by continuously flushing with ozonized air for a short period prior to and up to liftoff. Calibration of the detection system is required as close to launch as is practical. Calibration data will be acquired in the form of ozone concentration (ppmV) versus detector output. Flight data will yield detector output, from which may be derived the uncorrected ozone flux. Final data reduction via computer will yield ozone concentration (molecules per cm<sup>3</sup>) versus altitude. A sample computer output illustrating reduced ozone data is presented in Appendix D.

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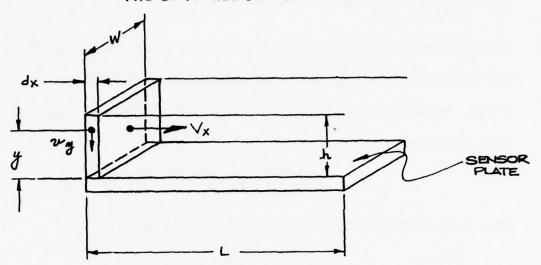
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### SPACE DATA CORPORATION PHOEMIX, ARIZOMA

APPENDIX A

THE DATA REDUCTION EQUATION



If an ozone molecule is a distance y from the sensor plate, then the time it takes the molecule to diffuse to the plate is:

$$\frac{y}{ty}$$
 =  $Vy \Longrightarrow ty = \frac{y}{Vy}$ 

where

If  $t_X$  is the time in which the elemental volume moves down the tube,

then

$$t_X = \frac{x}{V_X}$$
, where  $V_X = \frac{FV}{A}$ 

where Fy = flow rate

A = cross-sectional area of duct

(A = hW)

Then:

$$t_c = \frac{L}{V_x} = \frac{LA}{F_V} = critical time.$$
 This is

the time that the elemental volume is in contact with the sensor plate.

Now then, if  $t_y > t_c$ , then the ozone molecule a distance y from the

sensor plate will not be sensed (because it will take too long to reach the plate). Said another way, if ty  $\leq$  tc, then all the measurable ozone in the volume y W dx will be measured. The fraction of ozone molecules that moves toward sensor plate sensed to those present is  $f_M$ , where

$$f_M = \frac{\text{volume of ozone measured}}{\text{volume present}} = \frac{\frac{1}{6} \text{ y W dx}}{\text{h W dx}} = \frac{\text{y}}{6\text{h}}$$

(There is a 1:6 chance that direction of Vy will be toward sensor.)

Since 
$$y = \text{such that } t_y \le t_c$$

$$\implies \frac{y}{V_y} \le \frac{LA}{F_V} \implies y \le \frac{LAV_y}{F_V}$$
Since  $A = hW$ ,  $y \le LhW \frac{V_y}{F_V}$ 
Thus  $f_M = \frac{y}{6h} = \frac{LhW}{6h} \frac{V_y}{F_V} = \frac{LW}{6F_V} \frac{V_y}{6F_V}$ 

i.e., the fraction of ozone measured to ozone present is:

$$f_M = \frac{LW V_y}{6 F_V}$$

where  $f_M =$  the fraction

 $L =$  sensor length

 $W =$  sensor width

 $V_y =$  diffusion velocity

 $F_V =$  flow rate

What does all this mean?

When we measure ozone, we get a reading  $\theta$  which indicates how much ozone is measured. This is not necessarily the amount of ozone present. In fact, amount of ozone present =  $\frac{\text{amount of ozone measured}}{FM}$ 

i.e., 
$$F_M = \frac{\text{(ozone) measured}}{\text{(ozone) present}} \longrightarrow \text{(ozone) present} = \frac{\text{(ozone) measured}}{f_M}$$

Since 
$$F_M = LW V_y \delta F_V$$

(ozone present) = 
$$\frac{6 [(ozone) \text{ measured}] \text{ FV}}{\text{LW V}_y}$$

This is, essentially, the data reduction equation.

What we must do now is relate a calibration to altitude measurements.

During calibration we have:

(Oz) present = 
$$6 \times (Oz)$$
 measured  $\times \frac{F_V}{LW V_y}$   
 $V_y = k \lambda$ ,  
where  $\lambda = \text{inean free path}$   
 $k = \text{constant.}$ 

This says that the diffusion velocity is proportional to the mean free path; the greater the mean free path, the fewer the collisions and the faster the diffusion rate.

Thus, during calibration we have:

$$(Oz)_{present} = \frac{6 \times \frac{(Oz)_{measured} \times FV}{LW V_{y}}}{= \frac{6 \times \frac{(Oz)_{measured} \times FV}{LW k A}}$$

and we can plot:  $\theta$  versus (Oz) measured, as follows:



#### Calibration

θ	(Oz) <sub>measured</sub>
<b>e</b> 1	(No) <sub>1</sub>
θ <sub>2</sub>	(N <sub>o</sub> ) <sub>2</sub>
θ <sub>3</sub>	(N <sub>o</sub> ) <sub>3</sub>
•	
•	
0 <sub>n</sub>	(N <sub>o</sub> ) <sub>n</sub>

And we know: (Oz) present,  $F_V$ , L, W, and  $\lambda$ .

During flight we measure  $\theta$ , and we have:

-0	(Oz) <sub>measured</sub>
e <sub>1F</sub>	(N <sub>o</sub> ) <sub>1F</sub>
θ <sub>2F</sub>	(N <sub>o</sub> ) <sub>2F</sub>
9 <sub>3F</sub>	(N <sub>o</sub> ) <sub>3F</sub>
θ <sub>nF</sub>	(N <sub>o</sub> ) <sub>nF</sub>

Then:  $[(Oz)_{present}]_{flight} = 6x [(oz)_{measured}]_{flight}$ 

(F<sub>V</sub>)flight

We can now relate flight data to calibration, as follows:

$$\frac{[(Oz)_{present}]_{flight}}{[(Oz)_{present}]_{cal}} = \frac{\frac{6 \text{ FV}}{flight}}{\frac{1 \text{ Wk } \lambda \text{ flight}}{1 \text{ Flight}}} \times \frac{[(Oz)_{measured}]_{flight}}{[(Oz)_{measured}]_{cal}}$$

We will now let  $[(Oz)_{measured}]_{flight} = [(Oz)_{measured}]_{cal}$ , i.e.,  $\theta_{flight} = \theta_{cal}$ .

L, W, and k are constant, and not functions of altitude.

Equation reduces to:

$$\frac{[(Oz)_{present}]_{flight}}{[(Oz)_{present}]_{cal}} = \frac{(F_V)_{flight} \lambda_{cal}}{\lambda_{flight} (F_V)_{cal}}$$

or

$$[(Oz)_{present}]_{flight} = [(Oz)_{present}]_{cal} \times \frac{(FV)_{flight}}{(FV)_{cal}} \times \frac{\lambda cal}{\lambda flight}$$

This is the data reduction equation.

Thus, the data reduction equation:

[(Oz) present flight = [(Oz) present cal 
$$\times \frac{(F_V)_{flight}}{(F_V)_{cal}} \times \frac{\lambda cal}{\lambda flight}$$

where

[(Oz)<sub>present</sub>]<sub>cal</sub> = number density of ozone in lab that produced the same 
$$\theta$$
 reading as we get at altitude

 $(F_V)_{cal}$  = calibration flow rate

 $\lambda_{cal}$  = mean free path at calibration altitude

# SPACE DATA CORPORATION TEMPE, ARIZONA APPENDIX B

#### BLOWDOWN TEST FLOW RATE DERIVATION

Volumetric flow rate will be determined using the vacuum chamber pressure versus time curve, the known (constant) volume of the vacuum chamber, and the assumptions that the air acts as an ideal gas and the temperature remains constant.

Thus, the equation of state for an ideal gas can be used:

$$P_2 = \rho RT$$

where

By definition, 
$$\varrho = \frac{m}{V}$$
, where  $m = mass$  of air in vacuum chamber  $V = chamber$  volume

Thus, 
$$d e = \frac{1}{V} dm (V is constant)$$

Since 
$$P_2 = PRT$$
,

or,

$$dP_2 = \frac{RT}{V} dm$$

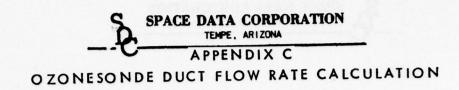
$$\frac{dm}{dt} = \frac{V}{RT} \frac{dP_2}{dt} = \frac{V}{entering chamber} = P_V$$

Thus, 
$$\rho F_{V} = \frac{V}{RT} \frac{dP_{2}}{dt}$$



$$F_{v} = \frac{V}{\varrho RT} \frac{d P_{2}}{dt}$$
Since 
$$P_{2} = \varrho RT \text{ from equation of state,}$$

$$F_{v} = \frac{V}{P_{2}} \frac{dP_{2}}{dt}$$



The following is an excerpt from SDC TM-1414, "Ozonesonde Duct Flow Rate Calculation."

#### 2.7 Final Flow Rate Equation

The results of Sections 2.1 through 2.7 are conglomerated to achieve the technique for calculating the flow rate through the ozonesonde sampling duct at a given altitude. The solution is as follows:

In general,

$$F_{V} = \frac{A \int \sqrt{\frac{P_{\infty}}{P_{\infty}}} \left(1 - \frac{P_{V}}{P_{T}}\right)^{7}}{\sqrt{A L_{F} + L_{M} + 0.5 \left(\frac{A}{A_{exit}}\right)^{2}}} + K_{F} \left(\frac{1 + 2.507 \frac{d}{2}}{1 + 3.095 \frac{d}{2}}\right) \left(1 - \frac{P_{V}}{P_{T}}\right)$$

Before the final solution can be achieved, we must evaluate the compressibility  $(\beta)$ , determine whether flow is laminar or turbulent (and thereby establish  $\ll$ ), and we must determine whether the flow is in the continuum or transition flow regime.

The solution thus is achieved by trial and error and is best achieved via computer.

The quantities A, A<sub>exit</sub>, L<sub>F</sub>, L<sub>M</sub>, d, and K<sub>F</sub> are functions of the duct configuration and are constant throughout the flight.

The quantities  $P_{\infty}$  ,  $P_{\infty}$  , and  $\lambda$  are functions of the altitude in question.

 $P_V$  and  $P_T$  are calculated as functions of  $P_\infty$  and sonde fall velocity,  $U_\infty$  as given in Section 2.1.

L and P are functions of the flow rate. Therefore, their values must be assumed to achieve the first approximation. The first approximation will give us an idea of whether the flow is laminar or turbulent and of what the compressibility may be.

TEMPE. ARIZONA

The solution technique is outlined as follows:

- 1) Using the methods of Section 2.1, calculate  $\frac{P_V}{P_T}$
- 2) Evaulate  $oldsymbol{eta}$  , as follows:

If 
$$\frac{P_V}{P_T} > .84$$
,  $\beta = 1$ .

If 
$$\frac{P_V}{P_T} < .63$$
,  $\beta = 0.7936$ .

If 
$$.63 \le \frac{P_V}{P_T} \le .84$$
,  $(\beta = 4.2404) \left(\frac{P_V}{P_T} - .63\right)^2 + 0.7936$ 

- 3) Let ∞ = 1.
- 4) Determine Po and Co for the altitude in question.
- 5) Calculate

$$\frac{A\beta \sqrt{\frac{P_{00}}{P_{00}} \left(1 - \frac{PV}{P_{1}}\right)^{1}}}{\sqrt{\propto L_{F} + L_{M} + 0.5 \left(\frac{A}{A_{exit}}\right)^{2}}} = F_{i}$$

6) Calculate M<sub>1</sub>, the flow mach number at entrance

where F, is the quantity evaluated in Step 5),

a<sub>co</sub> = speed of sound at altitude in question,

A:n = duct entrance area

7) If  $M_1 < 1$  and if  $\beta = 1$ , calculate Reynolds number per Step 8).

If  $M_1 < 1$  and  $\beta \neq 1$ , then change  $\beta$  to 1 and recalculate  $F_1$ .

TEMPE, ARIZONA

8) If 
$$M_1 \ge 1$$
 (or if  $M_1 < 1$  and  $\beta = 1$ ),
$$R_e = \frac{F_i}{A} \frac{\rho_{\infty}}{\mu_{\infty}} d = \text{Reynolds Number}$$

- 9) If  $R_e \ge 800$ , flow is turbulent and assumption that c=1 was valid
- 10) R<sub>e</sub> = new Reynolds Number. If R<sub>e</sub> is within 10% of the old Reynolds number, Lapproximation is close.
- 11) Calculate the ratio  $d/2\lambda$  , the ratio used to determine the flow regime.
- 12) If  $d/2\lambda = \geq 100$ , continuum flow exists, and  $F_V = F_i$ .
- 13) If  $d/2 = \leq 0.1$ , purely free molecular flow exists, and  $F_V = K_F \left(1 \frac{P_V}{P_T}\right)$ .
- 14) If  $0.1 < \frac{d}{2\lambda} < 100$ , transitional flow exists, and

$$F_V = F_i + Z K_F \left(1 - \frac{P_V}{P_T}\right)$$
, where  $Z = \frac{1 + 2.507 d/2 \lambda}{1 + 3.095 d/2 \lambda}$ 



 $F_V$  = flow rate at the altitude in question

A = duct cross-sectional area (in sensing chamber)

A duct exit area

A<sub>in</sub> = duct entrance area

d = duct hydraulic radius (in sensing chamber)

 $L_F$  = friction factor

LM = momentum loss factor

 $K_F$  = duct conductance

Poo = ambient pressure at altitude

σ = ambient air density at altitude

 $\mathcal{U}_{\infty}$  = viscosity of air at altitude

a mean free path at altitude

 $a_{\infty}$  = speed of sound at altitude

U<sub>co</sub> = sonde fall velocity at altitude

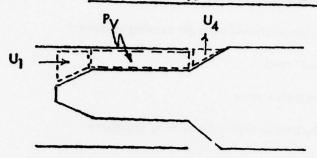
P<sub>V</sub> = Venturi pressure

 $P_T$  = total pressure incident to duct =  $P_{\infty}$  +  $\frac{1}{2} \left( \frac{1}{\infty} \right) \left( \frac{1}{\infty} \right)$ 

L = friction parameter

 $\varphi$  = compressibility parameter

### 2.1 Calculation of Py, the Venturi Pressure



Assume isentropic flow (no losses). Flow characteristics can be determined using isentropic flow tables.

ARAT1 = 
$$\frac{A_4}{A^*}$$
. If  $A^* > A_{throat}$ , then  $M = 1$  in throat.

Thus, for all ARATI such that  $\frac{A_4}{A^*} < \frac{A_4}{A_{throat}}$ , M = 1 at throat.

$$(A^* > A_{throat} \Rightarrow \frac{A_4}{A^*} < \frac{A_4}{A_{throat}}$$
.)

From the Appendix,  $A_{throat} = .2167 \text{ in}^2$  and  $A_4 = .7854 \text{ in}^2$ . Thus,

$$A_{\text{throat}} = A_2 = 0.2167 \text{ in}^2, \qquad \frac{A_4}{A_2} = \frac{0.7854}{0.2167} = 3.6244$$

.. For all ARAT1, such that  $\frac{A_4}{A^*}$  < 3.6244, M = 1 at throat.

This corresponds to  $\frac{P_4}{P_t}$  of < .982. Thus, for all  $\frac{P_4}{P_t}$  < .982,

 $P_V = 0.5283$  PT. Since P4 =  $P_{\infty}$  , M = 1 at throat for  $\frac{P_{\infty}}{P_T}$  < .982.

For  $\frac{P_4}{P_t} \ge .982$ ,  $\frac{A_4}{A^*} \ge 3.6244$ , subsonic flow exists in throat, and  $P_V$  is found using isentropic flow tables.

Summary of calculation of PV using isentropic flow tables:

- 1) Calculate PRAT11 =  $\frac{P_{\infty}}{P_{T}}$  If PRAT11 < .982,  $P_{V}$  = .5283  $P_{T}$ .
- 2) Look up PRAT11 in isentropic flow tables. Find corresponding ARAT11 (ARAT11 =  $A_4/A^*$ ).
- 3) Calculate ARAT22, where ARAT11 = ARAT11/3.6244.
- Look up ARAT22 in isentropic flow tables (subsonic section).
   Find corresponding PRAT22.
- 5)  $PRAT22 = \frac{P_V}{P_T}$ . So  $P_V = PRAT22*P_T$ .



### SAMPLE OZONE PROFILE REDUCED DATA

BZONES6NUE CONFIGURATION PARAMETERS	FAREA # 0.2167 IN**2	SAMPLING CUCT ENTRANCE AREA = 0.50320E-04 M**2 SAMPLING CUCT EXIT AREA = 0.67097E-04 M**2 SENSING CHAMBER CROSS-SECTIONAL AREA = 0.80645E-04 M**2 SENSING CHAMBER HYDRAULIC RADIUS = 0.56388E-02 METERS	55   PARAMETER		THE PACE IS BEST QUALITY PRACTICAL
BZONESONUE CONFIGURA	VENTURI THEGAT AREA VENTURI EXIT AREA	SAMPLING DUCT ENTRANCE AREA SAMPLING DUCT EXIT AREA SENSING CHAMBER CRUSS-SECTIONSING CHAMBER HYDRAULIC R	FRICTION LESS PARAMETER MAMENTUM LOSS PAKAMETER DUCT CONDUCTANCE	D-1	THIS PAGE IS BEST QUALITY PRACTICAL FROM COPY FURNISHED TO DDG

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54000.000	0.473CE+00	00+30569.0	259 3000	322.9500	AI.
53000.000	0.5380E+0C	0.71805+00	260.7000	323 8300	1
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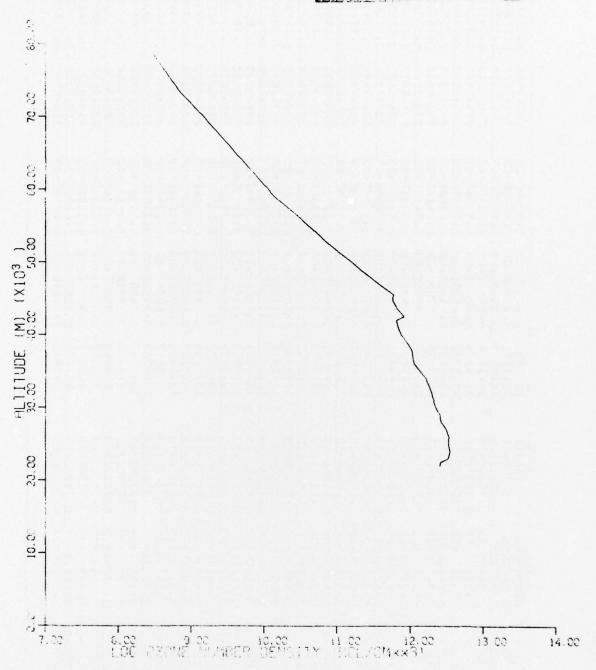
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9		.5761	.4118	211.8639	0.1929E+00	0.32675-05	205,4698	.1386E-0
ń	-2035E-02	•6362	0.4503E+09	223.0475	0.2073E+00	0.3499E-05	206.4460	0.1392E-05
Š	20475-02	0.7207E-01	0.4846E+09	231 • 5577	0.2269E+00	0.3807E-05	207 - 4228	1397E-0
9	20595-02	<b>•8079</b>	0.5237F+09	239,1090	0.2465E+00	0.4114E-05	208 • 3995	0.1403E-05
Ö	2069E-02	•8976	0.5689E+09	. 242.7000	0.2660E+00	0.4422E-05	209.3763	0.1409E-05
00	2079E-02	~	0.6219E+09	245.7612		0.4730E-05	210.3530	0.1414E-05
00 00	20941-02	1116	0.6694F+09	252.7159		0.5138E-05	211,3305	0.1420E-05
73000.00	2109E-02	1251	0.7378E+09	260.0000	0.3384E+00	0.5545E-05	212.3080	0.1425E-05
00	2122E	0.1387E+00	0.8272E+09	262.5000		0.5953E-05	213.2855	0.1431E-05
72000.00	2135	0.1527£+00	0.9320F+09	265.0000		0.6360E-05	214,2630	0.1436E-05
0 00	2154E	0.17156+00	0.1032E+10	265.0030	0.4265E+00	0.6882E-05	215.5935	0.1444E-05
0	2171E	•1908	0.1147E+10	265.0000	0.4618E+00	0.7403E-05	216.9240	0.1451E-05
-	21885	•2105	0.1278F+10	262.5000	0.4971E+00	0.7925E-05	218,2545	0.14595-05
00 0	2216E	•2360	0.1439E+10	260.0000	•	0.8668E-05	219.5850	0.1501E-05
ò	2237E-02	0.25685+00	0.1581E+10	253.2735		0.9178E-05	220.9550	0.1518E-05
00	2256E-02	1777	0.1744E+10	247.2294		0.9687E-05	222,3250	0.15356-05
00	22746-02	.3019	0.1937E+10	243.6616		0.1030E-04	223.6950	0.1548E-05
68000.00	22915-02	0.32642+00	0.2161E+10	239.7343	0.7444E+00	0.1091E-04	225.0650	0.1562E-05
7	23135-02	0+3573E+00	0.2378E+10	235.0475	0.8005E+00	0.1162E-04	226.4360	0.1573E-05
00	2333E-02	.3887	0.2626E+10	229 • 9371	0.8565E+00	0.1234E-04	227.8070	0.1585E-05
5	2359E-02	0.42545+00	0.2918E+10	224 • 17 46	0.9228E+00	0.1310E-04	229-1780	0.1596E-05
7	2383E-02	• 4627	0.3256E+10	218,3462	0.9891E+00	0-1387E-04	230.5490	0.160ZE-05
2	24055	•5061	0.3578E+10	211-9359	0.1055E+01	0.1479E-04	231.9208	0.1614E-05
65000.00	2426E-02	0.5502E+00	0.3946E+10	204.5884	0.1122E+01	0.1570E-04	233.2925	0.1621E-05
00	2453E-02	•6093	•	195,7500	0.1203E+01	0.1683E=04	234.6643	0.1623E-05
00	36	.6701E	0.4885E+10	186.9316	0.1285E+01	0.1795E-04	236.0360	0.1625E-05
3500.00	1.1	0.7424E+30	5	180.0917	1377		237 • 4088	0.1625E-05
$\mathbf{c}$	2536F-02	•	•	173,2910	7	0.2050E-04	238-7815	0.1625E-05
2500.00	67E	• 906	0.6619E+10	52	0.1575E+01	0.2197E-04	240 • 1543	0.1626E-05
	598E	0.9983E+00	0.7387E+10	6	0.1683E+01	0.2345E-04	241.5270	1627E-0
1500	631E	9		154.4100	0.1805E+01	.2514E-0	242.9005	0.1627E-05

4 244.2740 0.1628E-0 4 245.6475 0.1629E-0 4 247.0210 0.1630E-0	4 248.3953 0.1639E-0	4 249.7695 0.1648E-0	4 25101436 U01030E-2	4 252.5160 0.1670F-0	4 255.2685 0.1676E-0	4 256.6438 0.1679E-0	4 258.0190 0.1681E-0	4 259.3953 0.1678E-0	4 260.7715 0.1676E-0	4 262-1478 0-1678E-0	4 263.5240 0.1680E-0	4 264.9008 0.1684E-0	4 266.2775 0.1688E-0	4 267.6543 0.1691E-0	4 269.0310 0.1695E-0	4 269.4358 0.1698E-0	4 269.8405 0.1701E-0	3 270.2453 0.1702E-0	3 270.6500 0.1703E-0	3 270.6500 0.1699E-0	3 270.6500 0.1694E-0	3 270.6500 0.1691E-0	3 270.6500 0.1687E-0	3 269.7188 0.1691E-0	3 268.7875 0.1696E-0	3 267.8563 0.1701E-0	3 266.9250 0.1706E-0	3 265.5445 0.1702E-0	3 264.1640 0.1698E-0	3 262.7835 0.1692E-0		3 261.4030 0.1685E-0	3 261.4030 0.1685E-0 3 260.0218 0.1679E-0	3 261.4030 0.1685E-0 3 260.0218 0.1679E-0 3 258.6405 0.1672E-0	3 261.4030 0.1685E-0 3 260.0218 0.1679E-0 3 258.6405 0.1672E-0 3 257.2593 0.1670E-0	3 261.4030 0.1685E- 3 260.0218 0.1679E- 3 258.6405 0.1672E- 3 257.2593 0.1670E- 3 255.8780 0.1667E-
	.3263E	40.	30000	7 4	. 4395E	.4691E	.4986E	.5343E	.5700E	•6088E	•6475E	.6898E-	.73	· 7806E-	.83	·8836E-	.9381E-	.1001E-	·1064E-	.1140E-	0.1217E-	0.1304E-	0.1392E-	0.1482E-	0.1572E-	0.1672E-	0.1772E-	0.18	0.2025E-	0.2175E-	DATE O	0.63636	0.2499E	0.2674E-	0.2674E-	0.2674E- 0.2674E- 0.2865E- 0.3056E-
0.1927E+01 0.2065E+01	·2361E+	.251	3000	2000	. 3263E	•3492E	• 3722E	• 3977E	• 4232E	.4527E	· 4823E	•	•	•	·6230E+0	•	•7087E+0	•	•	-	•9147E	•9774E	•1040E	•1112E	•1184E	•1264E	•1345E	•1436E	•1528E	•1633E	•1738E		•1858E	.1858E+0	.1858E .1979E .2117E	1858E 1979E 2117E
148.8325	33.7	30.5	101	17.4	11,8	08 • 2	~	01 . 8	200	C	SI	00	$\boldsymbol{\sigma}$	+1	D	m	10	-	$\infty$	4	a	_	S.	O	O	$\infty$	$\infty$		N	~	~		-	AN	-IN M	44.7730 44.3731 41.9273
0.9021E+10 .0.1004E+11	1237E+1	•1368E	18175+1	7101.	•2363F+1	•2711E+1	•3110E+1	·3527F+1	+3898E+	• 4556E+1	.5196E+1	·5870E+1	·6627E+1	•7608F+1	·8806E+1	•1010E+1	·1163F+1	·1347E+1	•156CE+1	•1791F+1	·2054E+1	·2358E+1	·2742F+1	·3196E+1	•3715E+1	· 4320E+1	•5058E+1	.5948E+1	•5786E+1	.5890E+1	•6235E+1		•6712E+1	.7405E+1	.7405E+1 .8139E+1	0.6712E+12 0.7405E+12 0.8139E+12 0.6451E+12
0.1219E+01 0.135CE+01	•1623E+J	•1762	25011	7000	-2486E+0	•2739E+0	·2996E+0	•3315E+U	•3653E+0	. 4022E+0	· + 400F+0	·4854E+0	•5257E+0	.5764E+0	.6281E+U	•6890E+0	•7516E+U	·8245E+0	.9004E+0	•9972E+U	.109/E+0	·1214E+0	•1335£+0	•146CE+0	•1587E+0	•1731E+0	•1877E+0	•2072E+0	•1933E+0	•1890E+0	·1891E+0	The same of the sa	•1955E+0	•1955E+0 •2036E+0	.1955E+0 .2036E+0 .2112E+0	1955 2036 2112 2189
200	.2769L-0	0	0-10100	20195-0	-2958F-0	• 3002E - 0	.30456-	.3091E-D	.3135E-0	0	•3531E-0	.3282E-	0	.3384E-0	·3484E-0	·3490E-0	0-3	.3603E-0	0-3	•3722E-0	.3782E-0	0-1	•3910E-0	·3978E-0	· 4043E-0	• 41135-0	0.5	· 4252E-0	0-3	•3165E-0	·2887E-0		.2717E-0	.2717E-0 .2594E-0	.2717E-0 .2594E-0 .2468E-0	2717E 2594E 2468E 1708E
000	000	000	000			000	000	000	000	000	000	900	000	000	000	500	000	900	000	500	000	500	000	500	000	200	000	500	900	000	000		900	900	900	43500.00 43000.00 42500.00 42000.00

-	40000+00	0.1271E	0.218	•7499E+1	32.9893	9	.4049E-0	50.350	.164
	39500.00	0.1299E	0.242	<b>362</b>	32 • 7221	0.3148E+02		248.9670	32E
1	39000.00	0.1325E	0.267	•8893F+1	248	0.3359E+02	4695E-0	47.584	1626E
	38500.00	J.1353E	0.296	• 96		0.3604E+02	.5075E-0	4	.1617E
	38000.00	0.1352E	0.320	7	934	0.3849E+02	s,	244.8180	0
1	37500.00	J.1281E	0 • 330	·1049F+1	336	4135E+0	.5903E -0	243.4340	1599E
	37000.00	0.1221E-02	0.341(	•1077E+1	937	0.4420E+02	.6352E-0	242.0500	•1590E
	36500.00	J.1136E-02	0.345	0 • 1085E+13	26 • 3939	0.4753E+02	882E-	540.6660	0.1581E-05
-	36000.00	J-1080F-02	d	0.1125F+1	24.9562	9	7	239.2820	.1572E
	35500.00	J.1100E	0	0 • 1230E+1	24 • 7132	0.5474E+02	.8039E-0	237.8973	•1564E
	35000.00	0.1116E	0	0.13	24.4701	0.5863E+02	667E-	236.5125	•155E
1	34500.00	J.1132E	d	0.1482F+1	24.2270	0.6316E+02	0.9356E-0	235,1278	4
	34000.00	J.1141E	0	0 • 1634E+1	23 • 93 45	0.6768E+0P	_	233.7430	
	33500.00	0.1108E	0.5479E+02	0.1706E+13	22.9427	0.7295E+02	0.1090E-02	232.4298	0.1541E-05
-	33000.00	0.1077E	d	0.1794E+1	21 • 9509	0.7823E+02	٦	231,1165	
	32500.00	3.1042E	0	0 • 1888E+1	20.9591	0.8439E+02	_	229.8033	
	32000.00	0.9924E	0	0.19	19,9673	0.9054E+02	0.1368E-02	228.4900	0.1525E-05
	31500.00	J.9515E	d	0.2028F+1	18.9755	0.9768E+02	٦	227.9948	
D.	31000.00	0.9084E	0	Ö	17.9836	0.1048E+03	·	227.4995	
-1	30500.00	0.8602E	0	0.2147E	16,9918	0.1131E+03	0.1719E-02	227.0043	0.1520E-05
1	3000000	0.8190E	9	0.2234F	16.0000	•1215E+0		226 • 5090	
	29500.60	J.8120E	0	0.2382E	15.4951	•		226.0135	0.1507E-05
	29000-00	0.8061E	0.814	0.2556E+13	14 • 9902	0.1410E+03	0.2172E-02	225.5180	0.1502E-05
	28500.00	J.7892F	0.882	•2578F+1	4 0 4	0.1525E+03		225,0225	.1489E
	240000-00	0.7677E	0.941	•2673E+1	13,9803	0.1640E+03		224.5270	.1475E
	27500.00	J.7451E	0	0.2899E+13	3.4	0.1,776E+D3	-	224.0313	0.1473E-05
1	27000.00	J.7233F	0.104	+3122E+1	2,970	0.1913E+03		223 5355	.1470E
	26500.00	J.7086E	0•111(	9	12 • 4655	0	•	223.0398	•1468E
	26000.00	J.6934E	0.117	370E+1	1.961	. 2231	.3547E-0	"	0.1466E-05
1	25500.00	2.6675E	0.122	•3365E+1	1.470	•2418E+0	.3852E-0	222.0480	.1463E
	25000.00	3.6356E	0.1265E+0	+3367E+1	•978	.2605E+0	.4158E-0	"	• 1.4 60E
	24500.00	J. 6058E	0.128	0.3390E+13	4.0	0+3		21.	0.1474E-05
1	24000.00	0.5830F	0 • 1326E +0	•3469F+1	• 986	3030	4786	220 - 5600	•1471E
	23500.00	0.5675E	0 • 1 4 1 4 E + O	·3405E+1	.491	•3304	.5234	983	0.1469E-05
	23000.00	0.5518	0.1496	S	œ	579E	82E-0	9.5	•1466E-
	22500.00	0.5194F	0.1522E+0	•2593E+1	• 483	<b>3853</b>	46130E-0	219,0705	63E-0
		0.4673E	0.14	0.2533E+13	7.9898	0.4127E+03	0.6578E-02	8.574	0.1460E-05

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